The Association Between Bilateral Broad Jump Performance And The Sprint Profile

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THE ASSOCIATION BETWEEN BILATERAL BROAD JUMP PERFORMANCE AND THE SPRINT PROFILE

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Master’s Program in Kinesiology

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Dedication

For my family and friends that have supported, believed in me, and motivated me to reach my potential. And to my parents, thank you for being an example of hard work, dedication, and perseverance. This one is for you.
THE ASSOCIATION BETWEEN BILATERAL BROAD JUMP PERFORMANCE AND THE SPRINT PROFILE

by

SERGIO ALFONSO RODRIGUEZ JR, B.S.

THESIS

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I would like to thank the members of the Fitness Research Lab for mentoring me while I was working on my undergraduate degree and for allowing me to assist them with their various projects and learn so much. I would also like to thank my mentor, Dr. Dorgo, for advising me to continue my education and for showing me all the opportunities there are to grow professionally.
Abstract

Horizontal force application is vital to attain high velocities during sprinting. Similarly, broad jump performance is associated with the application of horizontal force to achieve greater jump distance. The video analysis-based sprint profile provides insight into multiple measures of sprint performance including maximal theoretical horizontal force, maximal theoretical velocity, optimal velocity, and maximal speed, which give an indication of overall sprint performance that is not reliant on spatiotemporal data alone. **PURPOSE:** To determine the relationship between broad jump distance and power output and the sprint profile of Division I track and field athletes.

**METHODS:** This study was conducted as a cross-sectional study among 19 male and female Division I Track and Field athletes from the University of Texas at El Paso. Subjects completed two countermovement broad jump trials and the distance from the start line to the closest landing mark was obtained to the nearest centimeter. Subjects then completed two 30-meter maximal sprints. A mobile device with the MySprint mobile application was used to obtain subjects’ sprint profile including maximal theoretical horizontal force, maximal theoretical velocity, optimal velocity, maximal speed, maximal power, maximal ratio of force, force-velocity slope, decrease in ratio of force. **RESULTS:** Significant correlations were found between broad jump distance and the maximal theoretical horizontal force ($r=0.573$, $p=0.01$; large), maximal power ($r=0.608$, $p=0.006$; large), and the maximal ratio of force ($r=0.548$, $p=0.015$; large). The resultant force (N) during the broad jump was significantly correlated with theoretical maximal velocity ($r=0.625$, $p=0.004$; large), maximal power ($r=0.607$, $p=0.006$; large), optimal velocity ($r=0.625$, $p=0.004$; large), and maximal ratio of force ($r=0.642$, $p=0.003$; large). The vertical force output (N) was correlated with maximal theoretical velocity ($r=0.594$, $p=0.007$; large), maximal theoretical power ($r=5.89$, $p=0.008$; large), optimal velocity ($r=0.594$, $p=0.007$; large)
and the maximal ratio of force ($r=0.646, p=0.003; \text{large}$). The horizontal force output during the broad jump was correlated with the maximal theoretical velocity ($r=0.625, p=0.004; \text{large}$), maximal power ($r=0.547, p=0.015; \text{large}$), maximal ratio of force ($r=0.574, p=0.010; \text{large}$) and optimal velocity ($r=0.625, p=0.004; \text{large}$). Simple linear regression analyses indicated that broad jump resultant force is the best predictor of 30 meter sprint completion time ($R^2=0.42$, $p<0.01$). A multiple linear regression indicated that a model containing both broad jump distance and horizontal force production during the broad jump can predict sprint completion time with 43% of the variance explained ($p=0.010$). **CONCLUSION:** To the author’s knowledge, this is the first study to explore the relationship between broad jump force output and the components of the sprint profile. Coaches and athletes can use this information to design training programs that focus on the development of horizontal force production by implementing exercises such as a broad jump. Furthermore, the broad jump may be used as a diagnostic tool to assess horizontal force production.
Table of Contents

Dedication ........................................................................................................................................ iii

Acknowledgements .......................................................................................................................... v

Abstract ......................................................................................................................................... vi

List of Tables .................................................................................................................................. x

List of Figures ................................................................................................................................ xi

Chapter 1: Introduction ................................................................................................................ 1
  Knowledge Gap .................................................................................................................. 4
  Purpose .............................................................................................................................. 4

Chapter 2: Literature Review ..................................................................................................... 5
  Force Application During Sprinting .................................................................................... 5
  The Sprint Profile ............................................................................................................... 6
    Sprint Profile Variables .............................................................................................. 8
  Bilateral Broad Jump and Sprint Performance ............................................................ 13

Chapter 3: Methods .................................................................................................................... 15
  Experimental design ......................................................................................................... 15
  Subjects ............................................................................................................................ 15
  Procedures ........................................................................................................................ 16
    30-meter Sprint ........................................................................................................ 16
    Broad Jump ............................................................................................................. 17
  Statistical Analyses ....................................................................................................... 18

Chapter 4: Results ..................................................................................................................... 20
  Correlations ...................................................................................................................... 20
  Regression Analysis ........................................................................................................ 20

Chapter 5: Discussion & Conclusion ......................................................................................... 25
  Limitations ....................................................................................................................... 26
  Conclusions ...................................................................................................................... 27
List of Tables

Table 1: Descriptives of anthropometrics and measures of interest (N=19).................................21
Table 2: Correlations between broad jump performance and 5-meter split times and the
components of the sprint profile. ........................................................................................................22
Table 3: Results of simple linear regression analyses between broad jump distance, vertical,
horizontal, and resultant force, and the 30 m sprint completion time..............................................23
Table 4: Results of the multiple linear regression analysis used to determine the best model to
predict sprint completion time (s).......................................................................................................24
List of Figures

Figure 1: Example of the force-velocity-power profile (Morin et al., 2019) ..............................10
Figure 2: Example of the power-velocity relationship (Hicks et al., 2020) .............................11
Figure 3: Example of the linear ratio of force-velocity relationship (Morin et al., 2019) ........11
Figure 4: Comparison of the force-velocity profiles of two subjects with similar completion time during the 20-m sprint (Morin et al., 2016) ..........................................................12
Figure 5: Definition of Sprint Profile variables (Morin et al., 2019) ......................................12
Figure 6: Camera and marker set up for sprint profile video analysis (MySprint) ..................17
Figure 7: Fast Fourier Transform plot used to determine cutoff frequency for the force data obtained during the bilateral broad jump. .................................................................18
Chapter 1: Introduction

Sprinting ability plays an important role in various sports. In track and field sprinting events the ability to achieve maximal sprinting acceleration and velocity is necessary for optimal performance. Linear sprinting performance is often assessed by determining the overall completion time over a given distance with the inclusion of measurements at different splits (Brown, Vescovi, & Vanheest, 2004). Although this method has previously been reported to be necessary to obtain an accurate assessment of sprinting ability (Brown et al., 2004), it is also imperative to measure and interpret kinetic determinants of sprint performance such as the rate of force development, force generation, and the proper application of forces because the ability to accelerate and achieve the highest velocity possible in the shortest amount of time is dependent on the proper application of force into the ground (Hicks, Schuster, Samozino, & Morin, 2020; Morin, Edouard, & Samozino, 2011). Measuring sprinting kinetics allows athletes and coaches to identify potential technical and mechanical deficiencies that may be hindering optimal performance which can then be addressed through proper strength training prescription.

Traditionally, obtaining kinetic measurements during sprinting would have required the utilization of force platforms. However, this method may not be the most practical way of collecting these data because it is limited by the number and arrangement of force platforms (Rabita et al., 2015), and force plates are expensive and limited in portability.

Assessing force application during sprinting is important for gaining a thorough understanding of an athlete’s sprint mechanics, efficiency, and technical characteristics. Samozino et al. (2016) introduced a novel mathematical model that estimates various kinetic and kinematic outputs to determine the force-velocity profile. This macroscopic method utilizes fundamental laws of motion applied to the center of mass to determine the force-power-velocity
relationships as well as the mechanical effectiveness during sprinting, and has been shown to be valid in comparison to force platform measurements (Morin, Samozino, Murata, Cross, & Nagahara, 2019; Samozino et al., 2016). Morin et al. (2019) fitted running velocity over time with an exponential function using the least-square regression method. This study showed that the exponential model provided a near perfect fitting of the horizontal velocity obtained by both laser measurement of speed (R²>0.996) and force plate measurement (R² >0.999) (Morin et al., 2019). Additionally, the horizontal force, vertical force, resultant force, and ratio of force values obtained were well fitted with the macroscopic method as manifested by the standard error of estimate (SEE) of 25.8±6.3 N, 37.6±13.7 N, 45.3±11.5 N and 2.23 ± 0.41%, respectively (Morin et al., 2019). This method of estimating the force-power-velocity profile during sprinting is more practical than force plate measurement because it consists of simple measurement of time-distance data using smaller, more efficient, and less expensive equipment such as photocell timing gates or a radar gun (Morin et al., 2019; Romero-Franco et al., 2017; Samozino et al., 2016). Recently, video analysis of sprint bouts has been performed through the use of the MySprint mobile application which is a more affordable and practical way to measure and calculate the mechanical outputs during the sprint acceleration (Romero-Franco et al., 2017). Although both time-distance and kinetic data can be obtained through timing gate and force plate data, video analysis with the MySprint mobile application provides a more efficient method for measuring and calculating the force-velocity profile, or sprint profile. The sprint profile consists of various measures of interest including theoretical maximal horizontal force, velocity, and power output, the ratio of force (horizontal force divided by the total resultant force during the stance phase of sprinting), optimal velocity, and maximal speed. These variables are imperative because they provide insight into an athlete’s mechanical effectiveness during sprinting and can
indicate if there are any weaknesses that need to be addressed through specific training programs. Sprint profiling aids coaches in understanding an athlete’s sprint quality by a comprehensive evaluation of the force-power-velocity relationship and information about the limits of the neuromuscular limits while accelerating. These limits include the theoretical maximal horizontal force at zero velocity, theoretical maximal horizontal velocity and the maximal power produced in the horizontal direction (Hicks et al., 2020). These measures and determining an athlete’s weaknesses helps strength and conditioning coaches identify which components of the force-velocity profile need to be addressed and which exercises and training modalities can be used to improve sprint performance. Since the sprint profile is a determination of an athlete’s ability to achieve high mechanical output during acceleration, this assessment can aid in identifying which approach to training is needed to improve an athlete’s maximal power output such as improving maximal horizontal force production at low speeds or at high speeds, or by training maximal power output with optimal loads (Hicks et al., 2020).

In addition to time-distance data, assessments of muscular power are useful for obtaining the necessary information to design practical and individualized training programs for sprinters. Performance assessments of the lower extremities are of particular interest for sprinters because the lower extremities are involved in running activities. In the literature, lower extremity power has been assessed by measuring performance in a variety of jumping tasks such as the bilateral vertical and standing broad jumps (Kale, Asçi, Bayrak, & Açıkada, 2009; Lockie et al., 2014; Lockie et al., 2016). Furthermore, broad jump distance has previously been associated with sprint completion time at various lengths (Hudgins, Scharfenberg, Triplett, & McBride, 2013; Kale et al., 2009; Loturco et al., 2015) as well as sprint acceleration and sprint velocity
(Peterson, Alvar, & Rhea, 2006). This association can be explained by the explosive nature of both the broad jump and sprinting and the rapid hip extension that is required for both activities.

**Knowledge Gap**

Although broad jump distance has been associated with sprint completion time, there is no information regarding the relationship between broad jump force output and sprint profile variables. Although previous literature has indicated that a greater broad jump distance is correlated with better sprint completion times, determining if there is an existing relationship between force and power outputs of the broad jump and the kinetic and kinematic variables of the sprint profile can provide a possible explanation as to why broad jump distance and sprint completion time are related. A greater amount of horizontal force produced in the broad jump would result in a better jump distance. Similarly, greater horizontal ground reaction forces produced during sprinting would result in more forward propulsion and better completion times. Although this seems to be hypothetically sound, the association between horizontal force production in the bilateral broad jump and specific measures of the sprint profile (such as maximal theoretical horizontal force, maximal theoretical velocity, and the ratio of force) has yet to be determined.

**Purpose**

The purpose of this study was to determine the association between broad jump distance and the sprint profile variables in collegiate track and field athletes. Additionally, the associations between peak resultant, horizontal, and vertical forces produced during the broad jump and the variables of the sprint profile were determined.
Chapter 2: Literature Review

**FORCE APPLICATION DURING SPRINTING**

Sprinting is a necessary skill used in a variety of sports such as soccer, American football, baseball and track and field. In track and field sprinting events the ability to achieve maximum sprinting velocity is important to achieve a favorable competitive outcome. Sprinting can be divided into three distinct phases: the positive horizontal acceleration phase, the maintenance of maximum speed, and the negative acceleration phase (Volkov & Lapin, 1979). The acceleration phase has been shown to contribute to overall performance during 100-meter sprints (Mero, 1988; Mero, Komi, & Gregor, 1992). Furthermore, the acceleration phase is further divided into a braking phase, during which negative horizontal ground reaction forces (GRF) are seen, and a propulsive phase with positive (propulsive) GRF (Hunter, Marshall, & McNair, 2005; Morin et al., 2011). During propulsion, both vertical and horizontal forces are applied to the ground with greater force application resulting in better sprint performance. However, it has been shown that producing forward acceleration during sprinting is not only dependent on the amount of force, but more importantly, on the orientation of the force. For example, Hunter et al. (2005) reported that relative horizontal impulse was the best predictor of sprint speed at the 16-meter mark of a sprint acceleration ($R^2 = -0.61$, $p < 0.001$). Additionally, during an investigation to determine the relationship between the ability to produce high amounts of horizontal force and sprint performance, significant correlations were found between horizontal force and maximal running speed ($r = 0.775$, $p < 0.01$) and mean 100-meter speed ($r = 0.736$, $p < 0.01$) while no significant associations were seen between the vertical or total force and these measures (Morin et al., 2011). Similarly, preventing a decrease in the ratio of force (horizontal force divided by net force) for a longer period of time was also correlated with
maximal sprint speed \( r = 0.0735, p < 0.01 \) and mean sprint speed \( r = 0.779, p < 0.01 \) (Morin et al., 2011). These results suggest that optimal sprinting performance can be achieved by applying high amounts of horizontal force and by one’s ability to maintain a high ratio of force as the sprinting velocity increases.

**THE SPRINT PROFILE**

The sprint completion time is an important indicator of sprint performance but is limited to just time-distance data and does not provide information regarding how an athlete is achieving a given completion time. Therefore, analyzing both the kinematics and kinetics of sprinting is important to gain an understanding of locomotion (Rabita et al., 2015). Traditional methods for measuring sprint kinetics can be experimentally challenging as measurement is limited by the amount of force platforms that are placed in series into the ground. Obtaining sufficient force data that accurately represents a sprint acceleration is challenging because of the amount of distance that is covered during a sprint acceleration (20-60 meters) (Morin et al., 2019; Rabita et al., 2015). Recently, a novel method has been introduced to measure and analyze kinetics during sprinting. This method incorporates basic laws of motion that are applied to the body’s center of mass and utilizes a mathematical model in which an inverse dynamic approach is applied to estimate the GRF during sprinting (di Prampero, Botter, & Osgnach, 2015; Samozino et al., 2016). As explained in Samozino et al. (2016), the horizontal force is computed using Newton’s second law of motion as highlighted in the equation below where \( F_H \) is the horizontal force applied to the center of mass, \( m \) is the sprinter’s mass in kilograms, \( a_H \) is the horizontal acceleration, and \( F_{aero} \) is the aerodynamic drag that is applied on the runner during sprinting.

\[
F_H(t) = m \cdot a_H(t) + F_{aero}(t)
\]
Samozino et al. (2016) further explained that in the vertical direction the initial upward movement from the starting crouched position to the standing running position is the only time where there is vertical movement of the center of mass, and, therefore, the vertical acceleration does not need to be calculated. Thus, the mean vertical GRF applied to the center of mass can be modeled to equal the runner’s body weight (di Prampero et al., 2015; Samozino et al., 2016).

This model is used to determine the force-velocity and power-velocity relationships through mathematical computation using anthropometric and spatiotemporal measures. More specifically, the sprint profile is calculated using the runner’s height in centimeters and body mass in kilograms, and distance-time or speed-time running data (Morin et al., 2019; Samozino et al., 2016). The distance and speed data can be measured using split times with timing gates, or with a laser measuring the motion of the body’s center of mass (Morin et al., 2019; Romero-Franco et al., 2017; Samozino et al., 2016). From this data, the sprint profile is computed and has been shown to accurately estimate the theoretical maximal force, theoretical maximal velocity, maximal power output, and the mechanical effectiveness of the application of GRF (Morin & Samozino, 2016; Romero-Franco et al., 2017; Samozino et al., 2016). Furthermore, Morin et al. (2019) validated this method against force plate data by comparing the sprint kinetics and force-velocity-power variables between the force plate data and the modelled data and showed that there is good agreement between the two methods. This study showed that the exponential model provided a near perfect fitting of the horizontal velocity obtained by both laser measurement of speed ($R^2>0.996$) and force plate measurement ($R^2>0.999$) (Morin et al., 2019). Additionally, the horizontal force, vertical force, resultant force, and ratio of force values obtained were well fitted with the macroscopic method as manifested by the standard error of estimate (SEE) of 25.8±6.3 N, 37.6±13.7 N, 45.3±11.5 N and 2.23 ± 0.41%, respectively (Morin et al., 2019).
In recent years, the MySprint mobile application which involves video analysis of sprint performance was developed for the measurement of the force-power-velocity profile. This method is a more practical and efficient for obtaining force, power, and velocity data because of the quicker set up. The MySprint video analysis uses markers, which serve as “gates”, placed at 5 m intervals over a 30 m distance as seen in Figure 3.1 (Romero-Franco et al., 2017). During the video analysis, one indicates when the athlete initiates the sprint and each time the athlete’s center of mass crosses each marker. This allows the app to calculate each split time and compute the force-power-velocity profile. Romero-Franco et al. (2017) conducted a validation study comparing results between video analysis of the sprint profile using the MySprint application, photocell timing gates, and a radar gun. The results showed a near perfect correlation between the mechanical variables produced by the MySprint application and the photocell timing gates (r=0.989-0.999, p<0.001) and the MySprint application and radar gun measurements (r=0.974-0.000, p<0.001).

**Sprint Profile Variables**

The sprint profile consists of various force, power, and velocity variables. Each variable describes a unique characteristic of an athlete’s sprinting mechanics and were previously defined by Morin et al. (2019) and summarized in Figure 5.

The theoretical maximal horizontal force indicates the maximal force output in the horizontal direction relative to body mass. Furthermore, this measure is correspondent with the initial push of the sprint acceleration, and a higher value indicates greater horizontal force production. The maximal theoretical horizontal force is the y-intercept of the linear force-velocity relationship (Figure 1).

The theoretical maximal running velocity is also extrapolated from the linear force-velocity relationship and identified as the x-intercept of the line (Figure 1). This variable indicates the
maximal running speed an individual can achieve. The theoretical value is higher than the actual maximal running velocity because it describes the maximal running velocity an athlete can reach if all internal and external resistances were equal to zero.

The maximal mechanical power output represents the highest amount of power an athlete can produce in the horizontal direction during the sprint acceleration. This value is calculated as the apex of the power-velocity relationship (Figure 2).

Additionally, the ratio of force is also calculated in the sprint profile. This variable is the direct measurement of the proportion between the total force production and the force directed in the forward direction and is indicative of the athlete’s overall mechanical effectiveness. It is computed as the ratio of step-averaged horizontal ground reaction force to the resultant force. Furthermore, the maximal value of the ratio of force is computed as the maximal value of the ratio of force during sprinting. This value depicts the theoretical maximal effectiveness of the force application. Lastly, the decrease in the ratio of force describes the athlete’s ability to limit the decrease in the mechanical effectiveness during sprinting at high speeds, or the ability to maintain a net horizontal force application. The rate of decrease in the ratio of force is calculated as the slope of the linear ratio of force-velocity relationship where a greater negative slope indicates a more rapid decline in the ratio of force, hence, a greater loss in mechanical effectiveness during sprinting (Figure 3).

Obtaining these measures can assist coaches and athletes in designing individualized training programs that will address any weaknesses that may be hindering sprinting performance. For example, Morin et al. (2016) explained that although two individuals may have similar 20-m sprint completion times, their force-velocity-power profiles may look different. In this example, shown in Figure 4, the Subject C displays a higher ability to produce maximal force into the ground in the horizontal direction, indicated by a greater maximal ratio of force and horizontal force compared to Subject D. However, Subject C also has a greater decrease in the ratio of force and a lower maximal velocity compared to Subject D, indicating that Subject C has the ability to produce a greater amount of force initially (sprint push-off) but is not able to maintain that horizontal force
production as velocity increases. The researchers further discuss that Subject D’s higher maximal velocity could be explained by their lesser decrease in the ratio of force. Furthermore, according to the authors, it appears that Subject D would benefit from a strength training program that is targeted at improving horizontal force application and increasing the maximal ratio of force.

Figure 1: Example of the force-velocity-power profile (Morin et al., 2019).
Figure 2: Example of the power-velocity relationship (Hicks et al., 2020).

Figure 3: Example of the linear ratio of force-velocity relationship (Morin et al., 2019).

Figure 4: Horizontal force-velocity-power profiles for 2 athletes. Both athletes display similar maximal horizontal power outputs and sprint times, yet different theoretical maximal force and velocity values (see slope).

Figure 2: Example of the power-velocity relationship (Hicks et al., 2020).
Figure 3 — Horizontal force–velocity profiles of 2 elite rugby union players (body mass for C, 108.8 kg, and D, 86.1 kg) obtained from maximal 30-m sprints. Both players reached their maximal running speed before the 30-m mark. Abbreviations: HZT-Pmax, maximal mechanical power output in the horizontal direction; Dref, rate of decrease in ratio of force with increasing speed during sprint acceleration; HZT-F0, maximal horizontal force production; HZT-V0, maximal running velocity.

Figure 4: Comparison of the force-velocity profiles of two subjects with similar completion time during the 20-m sprint (Morin et al., 2016).

Figure 5: Definition of Sprint Profile variables (Morin et al., 2019).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$HZT-F_0$ (N/kg)</td>
<td>Theoretical maximal horizontal force production as extrapolated from the linear sprint $F-V$ relationship; $y$-intercept of the linear $F-V$ relationship.</td>
</tr>
<tr>
<td>$HZT-V_0$ (m/s)</td>
<td>Theoretical maximal running velocity as extrapolated from the linear sprint $F-V$ relationship; $x$-intercept of the linear $F-V$ relationship.</td>
</tr>
<tr>
<td>$HZT-P_{max}$ (W/kg)</td>
<td>Maximal mechanical power output in the horizontal direction, computed as $P_{max} = F_0 \cdot V_0/4$, or as the apex of the $P-V$ 2nd-degree polynomial relationship.</td>
</tr>
<tr>
<td>$RF$ (%)</td>
<td>Ratio of force, computed as the ratio of the step-averaged horizontal component of the ground-reaction force to the corresponding resultant force.</td>
</tr>
<tr>
<td>$RF_{max}$ (%)</td>
<td>Maximal value of $RF$, computed as maximal value of $RF$ for sprint times $\geq 0.3$ s.</td>
</tr>
<tr>
<td>$D_{RF}$</td>
<td>Rate of decrease in $RF$ with increasing speed during sprint acceleration, computed as the slope of the linear $RF-V$ relationship.</td>
</tr>
</tbody>
</table>

Maximal force output (per unit body mass) in the horizontal direction. Corresponds to the initial push of the athlete onto the ground during sprint acceleration. The higher the value, the higher the sprint-specific horizontal force production.

Sprint-running maximal velocity capability of the athlete. Slightly higher than the actual maximal velocity. The theoretical maximal running velocity the athlete would be able to reach should mechanical resistances (ie, internal and external) against movement be null. It also represents the capability to produce horizontal force at very high running velocities.

Maximal power-output capability of the athlete in the horizontal direction (per unit body mass) during sprint acceleration.

Direct measurement of the proportion of the total force production that is directed in the forward direction of motion, ie, the mechanical effectiveness of force application of the athlete. The higher the value, the more important the part of the total force output directed forward.

Theoretically maximal effectiveness of force application. Direct measurement of the proportion of the total force production that is directed in the forward direction of motion at sprint start.

Describes the athlete’s capability to limit the inevitable decrease in mechanical effectiveness with increasing speed, ie, an index of the ability to maintain a net horizontal force production despite increasing running velocity. The more negative the slope, the faster the loss of effectiveness of force application during acceleration, and vice versa.
BILATERAL BROAD JUMP AND SPRINT PERFORMANCE

Like sprinting, the bilateral broad jump involves the rapid application of forces into the ground for optimal performance. Moreover, both sprinting and broad jump mechanics require the ability to explosively perform extension at the hip joint. This similarity has led to the investigation of the relationship between broad jump performance and sprinting ability. Previous literature indicates that there are existing correlations between bilateral broad jump performance and sprinting performance over various distances. For example, Lockie et al. (2016) showed strong negative correlations between standing broad jump distance and sprint completion time for 0-5m ($r=-0.55$, $p=0.01$), 0-10m ($r=-0.71$, $p<0.01$), and 0-30m ($r=-0.70$, $p<0.01$), indicating that better performance in an explosive movement such as the broad jump is correlated with better sprint acceleration. Additionally, a significant negative correlation between broad jump distance and 100m sprint completion time has been previously reported ($r=-0.81$, $p<0.01$) (Loturco et al., 2015). Furthermore, broad jump distance has been associated with 20 m sprint acceleration ($r=0.831$, $p=0.01$) and 40 m sprint velocity ($r=0.856$, $p=0.01$) (Peterson et al., 2006).

Although the relationship between broad jump distance has been associated with sprint performance, further research is warranted to determine if there are associations between broad jump performance and the various components of the sprint profile. The studies which have correlated broad jump distance with sprinting performance have not explored the association between force application during the broad jump and the sprint profile variables. Determining if there is an association between sprint profile variables and broad jump distance could shed light on the ability to produce horizontal force for a single, maximal repetition, and how that is related to certain variables such as the ability to maintain horizontal force application at increasing
velocity, maximal running velocity, and the ability to orient a greater amount of force in the horizontal direction.
Chapter 3: Methods

**Experimental Design**

This study was conducted as a cross-sectional study, in which all subjects attended one session and underwent all the physical assessments in a single day. The assessments were performed on an NCAA certified outdoor track. All tests and measurements were conducted by a team of experienced research members of the Fitness Research Lab at the University of Texas at El Paso (UTEP). Prior to the physical performance assessments, height was measured using a stadiometer to the nearest centimeter and mass was measured using a standard scale to the nearest hundredth of a kilogram. During both measurements, the subjects were asked to remove their shoes. Then, all subjects performed a standardized warm-up including general and specific warm-up drills. After the warm-up, the subjects performed two trials of the 30-meter sprints with three minutes of rest in between trials followed by two trials of the bilateral broad jump.

**Subjects**

This study included male (N=10; Height = 179.25 ± 5.4 cm; mass: 75.44 ± 7.01 kg) and female (N=9; height = 164.44 ± 7.03 cm; mass 59.95 ± kg) Division I track and field sprinters from the UTEP track team. An *a priori* power analysis conducted using G*power* (version 3.1, Universität Kiel, Germany) revealed that a minimum of 11 subjects are needed to obtain a power of 0.80 at alpha level 0.05 with a large correlation strength (r=0.70). This correlation coefficient was previously reported for the association between broad jump distance and sprint completion time by Lockie et al., (2016). All subjects were at least 18 years of age and completed an informed consent form approved by the Institutional Review Board of the University of Texas at El Paso. Subjects were free of musculoskeletal injuries to the lower extremities at the time of testing. Due to the safety protocols that must be followed because of the COVID-19 pandemic,
all subjects were screened for any signs and symptoms of COVID-19 through a mandatory questionnaire regarding recent exposure to infected individuals, and assessment of body temperature. Subjects that did not meet the required criteria were asked to leave the testing site immediately.

**PROCEDURES**

**30-meter Sprint**

Subjects performed two trials of the 30-meter sprints with three minutes of rest between trials. A video recording was obtained using an Apple iPad (Apple, Inc., Cupertino, CA, USA). Video files were then imported into a mobile application (MySprint) where completion times were calculated (Romero-Franco et al., 2017). To capture the video recordings of sprint trials, the iPad was set up in a fixed position in the frontal plane perpendicular to the running lane, at a height of 1.5 meters and 10 meters from the 15-meter marker (Figure 6), which is the proposed set up described in the MySprint application, and was suggested by Romero-Franco et al., (2017). As seen in Figure 6, six markers, which served as “gates”, were set up at 5 m intervals starting at the 5 m mark (last marker at 30 m). The subjects were instructed to start in a two-point stance with their front foot on the start line while remaining as still as possible. Furthermore, subjects were instructed to sprint maximally through the finish line. The recorder started video recording each trial before the “go” signal to capture the first propulsive movement of the sprint, which was used to determine the start time. The 5 m intervals were analyzed through the MySprint application by scrolling through the video file frame-by-frame and indicating the exact moment when the subject’s center of mass crossed each marker. The MySprint application was used to determine the five-meter split times over the 30 meters, and
the sprint trial with the fastest completion time and corresponding split times was used for statistical analyses.

**Figure 6:** Camera and marker set up for sprint profile video analysis (MySprint).

**Broad Jump**

Subjects performed two trials of the standing broad jump with the hands akimbo and with two minutes of rest between each jumping trial. The broad jump was performed by starting on two PASPORT 2-Axis Force Platforms with force data recorded at 1000 Hz using the Pasco Capstone Software (v.2.2.0). The subjects were instructed to stand on the force platforms with their hands on their hips and remain in a quiet stance until given the verbal cue “go” to initiate the countermovement broad jump. Furthermore, subjects were instructed to stick the landing or otherwise they repeated the trial. Force data from the left and right force platforms were summed up for analysis. The force data were analyzed using a custom MATLAB script and was filtered using a fourth-order low-pass Butterworth filter at 30 Hz. The cutoff frequency was determined by assessment of the Fast Fourier Transform Plot (Figure 7). The maximal horizontal and
vertical forces (N) were calculated as the highest amount of force produced during the broad jump (Loturco et al., 2015), and the peak resultant force was calculated using the Pythagorean Theorem. Peak force was defined as the highest force (N) produced during the concentric phase. Additionally, the jump distance was measured to the nearest centimeter using a standard measuring tape, and it was determined as the distance from the starting line to the subjects’ heel (Lockie et al., 2014). The jump trial with the longest distance was used for statistical analyses.

![FFT of Broad Jump](image)

Figure 7: Fast Fourier Transform plot used to determine cutoff frequency for the force data obtained during the bilateral broad jump.

**Statistical Analyses**

The broad jump and sprint profile data was exported into a master datasheet (Microsoft Excel, Microsoft, Redmond, WA) and then imported into SPSS 26 (SPSS, Inc., IBM, Armonk, NY) for analysis. Assessment of normality was conducted by using a Shapiro-Wilk test and through assessment of distribution of the histogram. Pearson r correlations were used to determine the relationships between the Sprint Profile variables and broad jump distance and horizontal, vertical, and resultant force. In the case that the data are not normally distributed, Spearman correlations were used. The magnitude of the correlation coefficients were considered
trivial ($r < 0.10$), small ($r = 0.10–0.29$), moderate ($r = 0.30–0.49$), large ($r = 0.50–0.69$), very large ($r = 0.70–0.89$), nearly perfect ($r = 0.90–0.99$), and perfect ($r = 1.0$) (Hopkins, 2009).

Simple linear regression analyses were used to determine the best predictor of sprint completion time among broad jump distance, vertical force, horizontal force, or resultant force. Furthermore, a multiple linear regression analysis was used to determine the best model to predict sprint completion time. Assumptions for regression analyses were assessed through the normal distribution of the independent variables, homoscedasticity of the residuals through quantile-quantile plots, and multi collinearity through the variance inflation factor (VIF < 10) for multiple regression. The best model for multiple regression was picked using a stepwise method, in which variables were added or removed until the best model was obtained, or collinearity was present.
Chapter 4: Results

Correlations

Among the sprinters, broad jump distance was positively correlated with the maximal theoretical force \((r=0.573, p=0.01; \text{large})\), maximal power \((r=0.608, p=0.006; \text{large})\), and the maximal ratio of force \((r=0.548, p=0.015; \text{large})\), and negatively correlated with 30-m sprint completion time \((r=0.543, p=0.016; \text{large})\). The broad jump resultant force \((N)\) was positively correlated with the theoretical maximal velocity \((r=0.625, p=0.004; \text{large})\), maximal power \((r=0.607, p=0.006; \text{large})\), optimal velocity \((r=0.625, p=0.004; \text{large})\), and maximal ratio of force \((r=0.642, p=0.003; \text{large})\), and negatively correlated with sprint completion time \((r=0.623, p=0.004; \text{large})\). The broad jump vertical force \((N)\) was positively correlate with the maximal theoretical velocity \((r=0.594, p=0.007; \text{large})\), maximal theoretical power \((r=5.89, p=0.008; \text{large})\), optimal velocity \((r=0.594, p=0.007; \text{large})\) and the maximal ratio of force \((r=0.646, p=0.003; \text{large})\), and negatively correlated with sprint completion time \((r=-0.621, p=0.005; \text{large})\). Lastly, the broad jump horizontal force \((N)\) was positively correlated with the maximal theoretical velocity \((r=0.625, p=0.004; \text{large})\), maximal power \((r=0.547, p=0.015; \text{large})\), maximal ratio of force \((r=0.574, p=0.010; \text{large})\) and optimal velocity \((r=0.625, p=0.004; \text{large})\) and negatively correlated with sprint completion time \((r=-0.581, p=0.009; \text{large})\). The correlations between broad jump distance, vertical force, horizontal force, and resultant force are shown in Table 2.

Regression Analysis

The results of the linear regression analyses indicated that the broad jump resultant force was the best predictor of 30 m sprint completion time \((R^2=0.415, p<0.01)\) (Table 3). Furthermore,
the model containing broad jump distance (cm) and horizontal force (N) was determined to be the best model for predicting sprint completion time (R²=0.435, p=0.01) (Table 4).

Table 1: Descriptives of anthropometrics and measures of interest (N=19)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>172.23</td>
<td>9.72</td>
<td>45.15</td>
<td>86.85</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.10</td>
<td>10.47</td>
<td>146.50</td>
<td>191.00</td>
</tr>
<tr>
<td><strong>30-meter sprint</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accel 0-5 m (s)</td>
<td>1.07</td>
<td>0.06</td>
<td>0.99</td>
<td>1.18</td>
</tr>
<tr>
<td>Accel 0-10 m (s)</td>
<td>1.81</td>
<td>0.09</td>
<td>1.68</td>
<td>1.98</td>
</tr>
<tr>
<td>Accel 0-15 m (s)</td>
<td>2.46</td>
<td>0.13</td>
<td>2.29</td>
<td>2.69</td>
</tr>
<tr>
<td>Accel 0-20 m (s)</td>
<td>3.07</td>
<td>0.17</td>
<td>2.88</td>
<td>3.37</td>
</tr>
<tr>
<td>Accel 0-25 m (s)</td>
<td>3.66</td>
<td>0.22</td>
<td>3.40</td>
<td>4.05</td>
</tr>
<tr>
<td>Accel 0-30 (s)</td>
<td>4.23</td>
<td>0.27</td>
<td>3.92</td>
<td>4.72</td>
</tr>
<tr>
<td><strong>Sprint Profile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F0 (N/kg)</td>
<td>12.78</td>
<td>1.23</td>
<td>10.39</td>
<td>15.20</td>
</tr>
<tr>
<td>V0 (m/s)</td>
<td>8.62</td>
<td>0.71</td>
<td>7.33</td>
<td>9.63</td>
</tr>
<tr>
<td>Pmax (W/kg)</td>
<td>27.59</td>
<td>3.90</td>
<td>20.49</td>
<td>33.98</td>
</tr>
<tr>
<td>FV Slope</td>
<td>-1.49</td>
<td>0.16</td>
<td>-1.81</td>
<td>-1.27</td>
</tr>
<tr>
<td>RFmax (%)</td>
<td>0.52</td>
<td>0.03</td>
<td>0.47</td>
<td>0.55</td>
</tr>
<tr>
<td>Drf (%)</td>
<td>-0.14</td>
<td>0.02</td>
<td>-0.17</td>
<td>-0.11</td>
</tr>
<tr>
<td>Vopt (m/s)</td>
<td>4.31</td>
<td>0.35</td>
<td>3.67</td>
<td>4.81</td>
</tr>
<tr>
<td>Max speed (m/s)</td>
<td>8.43</td>
<td>0.71</td>
<td>6.29</td>
<td>9.27</td>
</tr>
<tr>
<td><strong>Bilateral Broad Jump</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BJ Force (N)</td>
<td>1564.88</td>
<td>276.99</td>
<td>1043.87</td>
<td>2155.56</td>
</tr>
<tr>
<td>BJ Force (N/kg)</td>
<td>22.48</td>
<td>2.43</td>
<td>18.78</td>
<td>25.85</td>
</tr>
<tr>
<td>BJ Horizontal Force (N)</td>
<td>542.43</td>
<td>89.63</td>
<td>385.30</td>
<td>696.75</td>
</tr>
<tr>
<td>BJ Horizontal Force (N/kg)</td>
<td>7.81</td>
<td>0.90</td>
<td>5.96</td>
<td>9.12</td>
</tr>
<tr>
<td>BJ Vertical Force (N)</td>
<td>1491.50</td>
<td>266.36</td>
<td>974.64</td>
<td>2058.76</td>
</tr>
<tr>
<td>BJ Vertical Force (N/kg)</td>
<td>21.44</td>
<td>2.47</td>
<td>17.69</td>
<td>25.10</td>
</tr>
<tr>
<td>BJ Distance (cm)</td>
<td>218.95</td>
<td>20.28</td>
<td>191.00</td>
<td>254.00</td>
</tr>
</tbody>
</table>

F₀ = Theoretical maximal horizontal force, FV slope = Force-velocity slope, RFmax = Maximal ratio of force, Drf = Decrease in the ratio of force, Vopt = optimal velocity, BJ = Broad jump
Table 2: Correlations between broad jump performance and 5-meter split times and the components of the sprint profile.

<table>
<thead>
<tr>
<th>BJ Distance (cm)</th>
<th>BJ Force (N)</th>
<th>BJ Horizontal Force (N)</th>
<th>BJ Vertical Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>30-meter sprint</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5 m Time (s)</td>
<td>-.563*</td>
<td>0.01</td>
<td>-.583**</td>
</tr>
<tr>
<td>0-10 m Time (s)</td>
<td>-.614**</td>
<td>0.01</td>
<td>-.635**</td>
</tr>
<tr>
<td>0-15 m Time (s)</td>
<td>-.559*</td>
<td>0.01</td>
<td>-.647**</td>
</tr>
<tr>
<td>0-20 m Time (s)</td>
<td>-.578**</td>
<td>0.01</td>
<td>-.616**</td>
</tr>
<tr>
<td>0-25 m Time (s)</td>
<td>-.557*</td>
<td>0.01</td>
<td>-.624**</td>
</tr>
<tr>
<td>0-30 m Time (s)</td>
<td>-.543*</td>
<td>0.02</td>
<td>-.623**</td>
</tr>
</tbody>
</table>

Sprint Profile

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>p</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₀ (N/kg)</td>
<td>.573*</td>
<td>0.01</td>
<td>.378</td>
<td>0.110</td>
</tr>
<tr>
<td>V₀ (m/s)</td>
<td>.367</td>
<td>0.12</td>
<td>.625**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P_max (W/kg)</td>
<td>.608**</td>
<td>0.01</td>
<td>.607**</td>
<td>0.01</td>
</tr>
<tr>
<td>FV Slope</td>
<td>-.208</td>
<td>0.39</td>
<td>.133</td>
<td>0.59</td>
</tr>
<tr>
<td>RF_max (%)</td>
<td>.548*</td>
<td>0.02</td>
<td>.642**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DRF (%)</td>
<td>-.154</td>
<td>0.53</td>
<td>.202</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>V_opt (m/s)</td>
<td>.367</td>
<td>0.12</td>
<td>.625**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Max speed (m/s)</td>
<td>.084</td>
<td>0.73</td>
<td>.271</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Correlations between broad jump performance and 5-meter split times and the components of the sprint profile. 
F₀ = Theoretical maximal horizontal force, FV slope = Force-velocity slope, RFmax = Maximal ratio of force, 
DRF = Decrease in the ratio of force, V_opt = optimal velocity, BJ = Broad jump.
Table 3: Results of simple linear regression analyses between broad jump distance, vertical, horizontal, and resultant force, and the 30 m sprint completion time.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>β</th>
<th>CI</th>
<th>t</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJ Distance</td>
<td>-0.007</td>
<td>[-0.013, -0.001]</td>
<td>-2.444</td>
<td>0.026*</td>
<td>0.260</td>
</tr>
<tr>
<td>BJ Vertical Force</td>
<td>-0.001</td>
<td>[-0.001, 0.000]</td>
<td>-3.196</td>
<td>0.005*</td>
<td>0.375</td>
</tr>
<tr>
<td>BJ Horizontal Force</td>
<td>-0.002</td>
<td>[-0.003, -0.001]</td>
<td>-3.230</td>
<td>0.005*</td>
<td>0.380</td>
</tr>
<tr>
<td>BJ Force</td>
<td>-0.001</td>
<td>[-0.003, 0.000]</td>
<td>-3.472</td>
<td>0.003*</td>
<td>0.415</td>
</tr>
</tbody>
</table>

BJ = Broad jump, CI = 95% confidence interval
Table 4: Results of the multiple linear regression analysis used to determine the best model to predict sprint completion time (s)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>95% CI</th>
<th>$\beta$</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJ Distance</td>
<td>-0.004</td>
<td>[-0.010, 0.003]</td>
<td>-0.270</td>
<td>-1.244</td>
<td>0.232</td>
</tr>
<tr>
<td>BJ Horizontal Force</td>
<td>-0.001</td>
<td>[-0.003, 0.000]</td>
<td>-0.482</td>
<td>-2.226</td>
<td>0.041</td>
</tr>
</tbody>
</table>

Results of multiple linear regression analysis used to predict sprint completion time (s)  
$\text{(F (2,16) = 6.157, p=0.01, R}^2\text{=0.435)}$  
BJ = Broad jump, CI = 95% confidence interval
Chapter 5: Discussion & Conclusion

The aim of this study was to determine the relationship between broad jump performance and sprint performance as manifested by sprint completion time and the sprint profile. The findings showed a negative correlation between broad jump distance and sprint completion time which is in accordance with previous literature that reported strong negative correlations between broad jump distance and 30 m sprint completion time \((r=-0.70, p<0.01)\) (Lockie et al., 2016) and 100 m sprint completion time. \((r=-0.81 p<0.01)\) (Lockie et al., 2016; Loturco et al., 2015). The present study showed similar results to those seen in previous literature. Our results indicated that there was a large correlation between broad jump distance and 30 m sprint completion time \((r=0.57, p=0.01)\). The slight difference in the correlation coefficient could be due to the different sample among those in this study and previous literature. The present study sample consisted of sprinters while the sample used by Lockie et al. (2016) consisted of soccer players. Furthermore, Locke and colleagues only had male subjects, and the current study had both male and female subjects. Broad jump distance was also significantly positively correlated with theoretical maximal horizontal force, maximal power, and maximal ratio of force. It has previously been reported that longer broad jump distances are achieved through the application of increased forces in the horizontal direction (Peterson et al., 2006). Similarly, sprinting also requires increased horizontal force application for optimal performance because greater horizontal force output results in a greater ratio of force, hence more forward propulsion during sprinting (Hunter et al., 2005; Morin et al., 2011). The horizontal, vertical, and resultant forces measured during the broad jump were all significantly positively correlated with the theoretical maximal velocity, optimal velocity, maximal power, maximal ratio of force and negatively correlated with sprint completion time. This highlights the importance of the ability to apply force into the ground.
during both sprinting and horizontal jumping tasks. Perhaps of greater importance is the relationship between horizontal force application during each of these tasks since.

Previously, Hunter et al. (2005) reported that the best predictor of sprint speed during a 16 m sprint acceleration was the horizontal impulse generated, with 61% of the variance explained. In the present study, simple linear regression analyses showed that the resultant force measured during the broad jump was the best predictor of 30 m sprint completion time ($R^2=0.43$, $p=0.01$). Furthermore, a multiple linear regression was used to determine the model that best predicts sprint completion time. The results indicated that the model which included both broad jump distance and horizontal force during the broad jump was the best model to predict sprint completion time while accounting for 43% of the variance. This provides support to the contention that the orientation and not necessarily the magnitude of the force applied during sprinting, which is similar to the results seen by Morin et al. (2011) and Kugler and Janshen (2010).

**LIMITATIONS**

The sample in the current study consisted of athletes of varying competitive experience indicated by the number of years competing at the collegiate level. Additionally, the sample consisted of male and female subjects, so it is unclear if sex characteristics play a role in the associations seen in this study. The subjects did not follow a standardized warm-up protocol and were not familiarized with the broad jump testing protocol (hands-on-hips) and this could have affected their performance. Furthermore, this was a cross-sectional study and does not indicate of changes in the broad jump variables will result in changes in sprint performance over time. Future research can explore a longitudinal study to assess if improving broad jump performance will also improve sprint completion time.

26
CONCLUSIONS

To the author’s knowledge, this is the first study to explore the relationship between broad jump performance and force production to the components of the sprint profile. The results displayed strong correlations between broad jump horizontal force production and maximal theoretical velocity, maximal power, optimal velocity, and the ratio of force. Coaches and athletes can use this information to design training programs that focus on the development of horizontal force production by implementing exercises such as a broad jump. Although it remains unclear whether improving broad jump performance will result in better sprint completion time, one can speculate that by improving an athlete’s ability to appropriately orient the ground reaction forces during sprint performance can be improved. Furthermore, the broad jump may be used as a diagnostic tool to assess horizontal force production.
References


Vita

Sergio Rodriguez was born and raised in El Paso, Texas. He graduated from Silva Health Magnet High School in 2015 where his curiosity for the health sciences began. As a result of a lack of proper guidance during his high school years playing baseball, he developed a strong passion for learning how to improve his performance on the field through proper strength training. Sergio after graduating from high school he set out to study Kinesiology at the University of Texas at El Paso.

As an undergraduate student, Sergio continued to volunteer coaching his former baseball teammates, and began working as a personal trainer to gain practical experience in his field. After finishing his bachelor’s degree in 2019 he decided to pursue a master’s degree in Kinesiology. As a graduate student, Sergio continued to work as a personal trainer, strength and conditioning coach at a local gym, and as a field-work supervisor for the Golden Age Fitness Program at UTEP. Sergio also assisted in collecting data for various research projects, presented at local and regional conferences including the Texas Chapter of the American College of Sports Medicine conference. Additionally, Sergio was also a recipient of the Dodson Graduate Research Grant.

After completing his master’s degree, Sergio will continue his studies in the Doctor of Physical Therapy Program at the University of Texas at El Paso.

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